The cooling efficiency of electric heat pumps with less than a 65,000 Btu/h cooling capacity is rated according to the SEER value. The cooling efficiency of heat pumps with a cooling capacity of 65,000 Btu/h or more is rated according to its Energy Efficiency Ratio[5] or EER.

In general, heat pump cooling is rated according to the SEER or EER, and heat pump heating by an HSPF or COP. Since few residential buildings use heat pumps with an output capacity greater than 65,000 Btu/h, the Low-Rise Residential Standards only use SEER and HSPF ratings, not EER or COP.

Description of the Proposed Natural Gas Heat Pump Calculation Method

ANSI approved the *American National Standard for Performance Testing and Rating of Gas-Fired, Air Conditioning, and Heat Pumping Appliances, ANSI Z21.40.4 - 1994*, on May 23, 1994. ANSI Z21.40.4 establishes testing requirements, testing conditions, testing procedures, steady-state heating/cooling ratings, and heating/cooling seasonal performance parameters for residential air-source appliances. This standard is comparable to Air-conditioning and Refrigeration Institute (ARI) Standard 210/240-89, *Standard for Unitary Air-Conditioning and Air-Sources' Heat Pump Equipment,* which is used to determine the SEER and HSPF for electric heat pumps.

ANSI Z21.40.4 includes a bin method procedure to determine the heating and cooling seasonal performance parameters for air and water source appliances in residential applications. Performance is determined for each midpoint of outdoor temperature bins. These are weighted by the frequency of occurrence of outdoor temperatures within each bin range and then summed. The values for heating and cooling bin hours are separated into six climate regions plus a U.S. national average rating defined by the Department of Energy.

The actual input data for the York Triathlon[6] gas-fired heat pump model E2GE036N06401 (Outdoor Unit) are listed in Attachment A. The results from the ANSI Z21.40.4 simulations are seasonal output (kBtu), seasonal gas input (kBtu), and seasonal electric input (kWh). Attachment B contains the ANSI Z21.40.4 test results for

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Title 20 of the California Code of Regulations. British thermal units shall be converted to kilowatt-hours at the rate of 3,413 British thermal units per kilowatt-hour.

[5]   Energy Efficiency Ratio (EER) means the ratio of the cooling capacity of the air conditioner (heat pump), in British thermal units per hour, to the total electrical input in watts under test conditions specified in section 1603(b) and (c) of Title 20 of the California Code of Regulations.

[6]   The York Triathlon heat pump is the only gas-fired heat pump currently commercially available.

this gas-fired heat pump and which illustrates each step of the simulation and the corresponding calculations. The heating/cooling seasonal performance parameters[7] are tabulated in Table 1. The four regions (II, III, IV and V) are those that apply to California. The national average is shown for comparison.

The DOE-2.1E simulation model has the provision to estimate an energy budget for gas-fired heat pumps. The data required to determine the heating and cooling energy budget listed below and in Attachment A are specified in ANSI Z21.40.4:

- The steady-state capacity rating in Btu (Q)
- The steady-state gas input ratings in Btu (G)
- The steady-state auxiliary electric power input rating in Watt-hours (E)

Alternatively, the heating/cooling seasonal performance parameters derived from ANSI Z21.40.4 can be used to estimate cooling and heating efficiency of gas-fired heat pumps that can be used in a modified CALRES model. However, we must introduce new descriptors such as the seasonal heating-mode gas Coefficient of Performance (COP_{hg}), seasonal cooling-mode gas COP (COP_{cg}), seasonal heating-mode electric COP (COP_{he}) and seasonal cooling-mode electric COP (COP_{ce}).

Table 1
Seasonal Performance Parameters: York's Gas-Fired Heat Pump

DOE Region	SEASONAL HEATING			SEASONAL COOLING		
	SHO (kBtu)	SHGEC (kBtu)	SHEEC (KWh)	SCO (kBtu)	SCGEC (kBtu)	SCEEC (kWh)
Region II	24,064	19,435	350	69,934	50,664	940
Region III	40,428	33,406	611	46,623	33,776	626
Region IV	69,305	58,629	1,084	31,082	22,517	418
Region V	84,698	77,423	1,529	15,541	11,259	209
National Average	64,060	54,193	1,002	38,852	28,147	522

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[7] SCO = Seasonal Cooling Output (Btu)
SCEEC = Seasonal Cooling Electric Energy Consumption (Watt-hour)
SCGEC = Seasonal Cooling Gas Energy Consumption (Btu)
SHO = Seasonal Heating Output (Btu)
SHEEC = Seasonal Heating Electric Energy Consumption (Watt-hour)
SHGEC = Seasonal Heating Gas Energy Consumption (Btu). These parameters are determined in ANSI Z21.40.4.

COP_{hg} means the total heating output of a gas-fired heat pump in British thermal units during its normal usage period for heating divided by the gas input in Btu during the same period, as determined by using the test procedure specified in ANSI Z21.40.4.

COP_{cg} means the total cooling output of a gas-fired heat pump in British thermal units during its normal usage period for cooling divided by the gas input in Btu during the same period, as defined using the test procedure specified in ANSI Z21.40.4.

COP_{he} means the total heating output of a gas-fired heat pump in British thermal units during its normal usage period for heating divided by the electric input in Btu during the same period, as determined by using the test procedure specified in ANSI Z21.40.4. To convert electric input to Btu, multiply the estimate by 3.413 Btu/Wh.

COP_{ce} means the total cooling output of a gas-fired heat pump in British thermal units during its normal usage period for cooling divided by the electric input in Btu during the same period, as defined using the test procedure specified in ANSI Z21.40.4.

Equations 1 through 4, used to calculate the seasonal cooling and heating mode efficiencies for gas-fired heat pump are listed below:

$$COP_{heating-mode,\ gas} = \frac{SHO}{SHGEC} \tag{1}$$

$$COP_{cooling-mode,\ gas} = \frac{SCO}{SCGEC} \tag{2}$$

$$COP_{heating-mode,\ electric} = \frac{SHO}{SHEEC \times 3.413} \tag{3}$$

$$COP_{cooling-mode,\ electric} = \frac{SCO}{SCEEC \times 3.413} \tag{4}$$

Where: SHO = Seasonal Heating Output (Btu)
SCO = Seasonal Cooling Output (Btu)
SHGEC = Seasonal Heating Gas Energy Consumption (Btu)
SCGEC = Seasonal Cooling Gas Energy Consumption (Btu)
SHEEC = Seasonal Heating Electric Energy Consumption (Watt-hour)
SCEEC = Seasonal Cooling Electric Energy Consumption (Watt-hour)

Table 2 shows the COP_{hg}, COP_{he}, COP_{cg} and COP_{ce} for the gas-fired heat pump.

To determine cooling efficiency, ANSI Z21.40.4 requires using eight temperature bins with the same outdoor temperature frequency distribution for all climate regions. Therefore, the COP_{cg} is the same for all regions as shown in Table 2.

Table 2 shows that the average COP_{hg} for Regions II, III, IV and V (those representing California) is about 1.18 which is about the same as the national average rating (shown on Table 2). Staff therefore recommends that manufacturers use national average rating values to estimate COP_{hg}, COP_{he}, COP_{cg} and COP_{ce} for the gas-fired heat pump.

Table 2
York's Gas-Fired Heat Pump COP Values

DOE Region	HEATING-MODE		COOLING-MODE	
	GAS COP_{hg}	ELECTRIC COP_{he}	GAS COP_{cg}	ELECTRIC COP_{ce}
Region II	1.24	20.14	1.38	21.80
Region III	1.21	19.39	1.38	21.82
Region IV	1.18	18.73	1.38	21.79
Region V	1.09	16.23	1.38	21.79
National Average	1.18	18.73	1.38	21.81

The COP_{hg} and COP_{cg} results are used to estimate fuel input ratio (FIR) for heating and cooling respectively. The FIR, as shown below in Equations 5 and 6, is defined as the reciprocal of the gas COP times the reciprocal of the duct efficiency. The FIRs for heating and cooling will then be used to estimate the energy budget with the CALRES model.

$$FIR_{cooling} = [\frac{1}{COP_{cg}}] \; x \; [\frac{1}{\eta_{duct}}] \tag{5}$$

$$FIR_{heating} = [\frac{1}{COP_{hg}}] \; x \; [\frac{1}{\eta_{duct}}] \tag{6}$$

Where:
$FIR_{heating}$	=	Fuel Input Ratio for Heating
$FIR_{cooling}$	=	Fuel Input Ratio for Cooling
COP_{hg}	=	Seasonal Heating-mode gas COP
COP_{cg}	=	Seasonal Cooling-mode gas COP
η_{duct}	=	Duct Efficiency

The FIR calculation is based on site gas energy consumption and does not include auxiliary energy and the source energy multipliers as specified in modeling energy budget for spacing conditioning. Therefore, staff recommend introducing the electric input ratio (EIR) for heating and cooling to address the auxiliary energy. The EIR as shown in Equations 7 and 8 is defined as the reciprocal of the electric COP times the reciprocal of the duct efficiency. The COP_{he} and COP_{ce} results are used to estimate electric input ratio (EIR) for heating and cooling respectively.

$$EIR_{heating} = [\frac{1}{COP_{he}}] \; x \; [\frac{1}{\eta_{duct}}] \tag{7}$$

$$EIR_{cooling} = [\frac{1}{COP_{ce}}] \; x \; [\frac{1}{\eta_{duct}}] \tag{8}$$

Where:
$EIR_{heating}$	= Electric Input Ratio for Heating
$EIR_{cooling}$	= Electric Input Ratio for Cooling
COP_{he}	= Seasonal Heating-mode electric COP
COP_{ce}	= Seasonal Cooling-mode electric COP
η_{duct}	= Duct Efficiency

Table 3 shows the $FIR_{heating}$, $FIR_{cooling}$, $EIR_{heating}$, and $EIR_{cooling}$ for this specific model GFHP with a duct efficiency of 0.83 and 0.81 for heating and cooling respectively. The FIR and EIR are derived from the national average COPs in Table 2.

Table 3
York's Gas-Fired Heat Pump FIR and EIR Values[a]

HEATING-MODE		COOLING-MODE	
$FIR_{heating}$	$EIR_{heating}$	$FIR_{cooling}$	$EIR_{cooling}$
1.021	0.0643	0.895	0.0566

a. Assuming national average COPs from Table 2 and a duct efficiency of 0.83 for heating and 0.81 for cooling.

Staff proposes to add the gas-fired heat pump provision in the CALRES model by introducing both the FIRs and EIRs as expressed in equations 5 through 8. Specific inputs needed to demonstrate compliance are COP_{hg}, COP_{he}, COP_{cg} and COP_{ce}. Manufacturers would be required to follow testing procedures specified in ANSI Z21.40.4 and then run a bin method calculation to determine the national average results. The results from the ANSI Z21.40.4 simulations are used to calculate the COP_{hg}, COP_{he}, COP_{cg} and COP_{ce}. The following shows that gas-fired heat pumps meet the Source Seasonal Efficiency (SSE) rating for heating and cooling as established in the Alternative Calculation Method (ACM) and CALRES model. In the CALRES model, the Source Seasonal Efficiency for heating ($SSE_{heating}$) is defined as:

$$SSE_{heating} = \frac{1}{FIR_{heating} + EIR_{heating} \times Source\ Multiplier} \qquad (9)$$

Where: $FIR_{heating}$ = Fuel Input Ratio for Heating
        $EIR_{heating}$ = Electric Input Ratio for Heating
        Source multiplier[8] = 3

Assuming a duct efficiency of 0.83, the $FIR_{heating}$ and $EIR_{heating}$ for this specific gas-fired heat pump model are 1.021 and 0.0643 respectively. The SSE for this GFHP is about

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8   The Source Multiplier, from the Building Standards, assumes a electricity system efficiency average of 33% (1/Source Multiplier), or an average heat rate of 10,239 Btu/kWh, which is fairly representative of the current system in California and nationally.

0.83 which is higher than the gas furnace (SSE$_{heating}$= 0.647 = 0.78 times duct efficiency) and a electric heat pump (SSE$_{heating}$= 0.55 = 0.664 times duct efficiency).

For cooling equipment, both CALRES and the ACM use SEER to rate electric equipment and there is no provision for gas fired equipment. For this reason, we introduce Source Seasonal Efficiency for cooling (SSE$_{cooling}$) as defined below:

$$SSE_{cooling} = \frac{1}{FIR_{cooling} + EIR_{cooling} \; x \; Source \; Multiplier} \tag{10}$$

Where: FIR$_{cooling}$ = Fuel Input Ratio for Cooling
           EIR$_{cooling}$ = Electric Input Ratio for Cooling
           Source multiplier = 3

For this specific gas-fired heat pump the FIR$_{cooling}$ and EIR$_{cooling}$ are 0.895 and 0.0566 respectively. The SSE for this GFHP is about 0.95. That SSE is higher than the minimum standard level 10 SEER air conditioner (SSE$_{cooling}$= 0.79[9]). Therefore, the GFHP meets the minimum standards for heating and cooling.

Conclusions and Recommendations

Staff recommends that the gas-fired heat pump provision be added to the CALRES model by introducing both the FIRs and EIRs as expressed in equations 5 through 8. Specific inputs needed to demonstrate compliance are COP$_{hg}$, COP$_{he}$, COP$_{cg}$ and COP$_{ce}$. Manufacturers would be required to follow testing procedures specified in ANSI Z21.40.4 and then run a bin method calculation to determine the national average results. The results from the ANSI Z21.40.4 simulations are used to calculate the COP$_{hg}$, COP$_{he}$, COP$_{cg}$ and COP$_{ce}$. Therefore, gas-fired heat pumps could be used in new and existing residential developments, and their energy use could be calculated as part of the Building Efficiency Standards.

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[9]   SEER means the total cooling output of a central air-conditioner (heat pump) in British thermal units divided by the total electrical energy input in watt-hours. The unit of SEER is Btu/Wh. According to the CALRES model, the cooling EIR for electric air-conditioner equals 3.413 divided by SEER and then divided by duct efficiency. Therefore the EIR for an electric air-conditioner with SEER of 10 and a duct efficiency of 0.81 is about 0.421. Substituting the EIR and a source multiplier of 3 into Equation 10, the SSE becomes 0.79.

ATTACHMENT A: GAS HEAT PUMP DATA SHEET

Date: 2/23/95

HEATING INPUT DATA:

$Q_{ss}^{(K=1)}(47) =$ 22.5 (MBTUH)

$G_{ss}^{(K=1)}(47) =$ 15.1 (MBTUH)

$E_{ss}^{(K=1)}(47) =$ .28 (KW)

$Q_{Def}^{(K=1)}(35) =$ 19.1 (MBTUH)

$G_{Def}^{(K=1)}(35) =$ 15.0 (MBTUH)

$E_{Def}^{(K=1)}(35) =$ .280 (KW)

$Q_{ss}^{(K=1)}(17) =$ 13.8 (MBTUH)

$G_{ss}^{(K=1)}(17) =$ 13.8 (MBTUH)

$E_{ss}^{(K=1)}(17) =$ .320 (KW)

$Q_{ss}^{(K=i)}(17) =$ 23.5 (MBTUH)

$G_{ss}^{(K=i)}(17) =$ 21.1 (MBTUH)

$E_{ss}^{(K=i)}(17) =$ .390 (KW)

$Q_{Def}^{(K=2)}(35) =$ 40.5 (MBTUH)

$G_{Def}^{(K=2)}(35) =$ 34.2 (MBTUH)

$E_{Def}^{(K=2)}(35) =$ .510 (KW)

$Q_{ss}^{(K=2)}(17) =$ 34.4 (MBTUH)

$G_{ss}^{(K=2)}(17) =$ 31.7 (MBTUH)

$E_{ss}^{(K=2)}(17) =$ .540 (KW)

$Q_{ss}^{(K=2)}(7) =$ 30.6 (MBTUH)

$G_{ss}^{(K=2)}(7) =$ 30.5 (MBTUH)

$E_{ss}^{(K=2)}(7) =$ .630 (KW)

GHP Model: E2GE036N06401 Outdoor Unit

N2GED14H06401 Air-Handler

G2GE036S Coil

COOLING INPUT DATA:

$Q_{ss}^{(K=1)}(82) =$ 22.9 (MBTUH)

$G_{ss}^{(K=1)}(82) =$ 14.8 (MBTUH)

$E_{ss}^{(K=1)}(82) =$ .29 (KW)

$Q_{ss}^{(K=1)}(67) =$ 24.3 (MBTUH)

$G_{ss}^{(K=1)}(67) =$ 13.5 (MBTUH)

$E_{ss}^{(K=1)}(67) =$ .29 (KW)

$Q_{ss}^{(K=i)}(87) =$ 31.0 (MBTUH)

$G_{ss}^{(K=i)}(87) =$ 23.9 (MBTUH)

$E_{ss}^{(K=i)}(87) =$ .39 (KW)

$Q_{ss}^{(K=2)}(95) =$ 38.9 (MBTUH)

$G_{ss}^{(K=2)}(95) =$ 41.6 (MBTUH)

$E_{ss}^{(K=2)}(95) =$ .54 (KW)

$Q_{ss}^{(K=2)}(82) =$ 40.4 (MBTUH)

$G_{ss}^{(K=2)}(82) =$ 39.6 (MBTUH)

$E_{ss}^{(K=2)}(82) =$ .54 (KW)

CLH = Determined Locally

CCD = .25

DHR = Determine Locally (MBTUH)

HCD = .25

TOD = Determine Locally

DCF = 1.0

AUX.HTR.EFF = 82 (%)